January 20, 1995

Summary of Progress

The designs of a gas system for introducing water vapor and a photo-CVD reactor are demonstrated in this month. As mentioned in last report, water vapor has a great potential for the photon activation method. With a closed vessel, water vapor is carried by a stream of argon. The content of water vapor is adjusted and controlled by the flow rate of argon. A diamond growth reactor using pure photon activation is attractive for high purity diamond films with low energy consumption. The quality diamond films will be higher than those grown by microwave methods, in which high energy charged particles in the plasma may damage the films. Furthermore, the diamond grown in the microwave lamp were reported with highly oriented films last month. The trial for better films has not succeeded due to the overheating problem of the microwave system. The experimental work with the internal coupling will be done and studied systematically next month.

GAS SYSTEM FOR UV ENHANCEMENT OF DIAMOND GROWTH

According to the analysis of the previous report, water vapor and rare gases (argon will be used in the experiment) are introduced into the gas phase to demonstrate the UV enhancement of diamond growth. Rare gas excimers emit UV photons with very high efficiency. Water vapor has significant absorption and dissociation under UV irradiation. Therefore, the gas phase will consists of four species, H_2, CH_4, Ar, and H_2O.

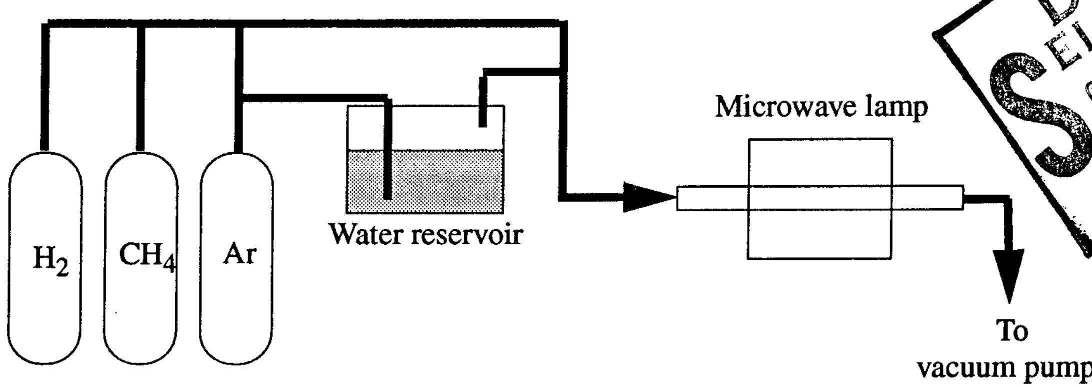

Figure 1. The gas system for introducing of water vapor.

Water vapor will be introduced by a rare gas stream as shown in Figure 1. The amount of water vapor carried by the argon stream can be estimated by the saturated vapor pressure at the water temperature. Thus, the content of water vapor can be adjusted by the flow rate of argon (or other carriers). As shown in Figure 1, argon flow is divided into two streams, one to the water reservoir to carry water vapor, and the other to the gas line of hydrogen and methane. This design makes the

argon concentration independent of the water vapor content. In the experiment, the optimal volumetric ratio of these four species will be determined.

DESIGN OF A PHOTO-CVD REACTOR

Gas activation and the heated substrate are two basic requirements for high quality diamond growth. As mentioned in the previous report, both processes can be greatly enhanced by using photons. The various photo-CVD techniques are indicated in Figure 2. The photon sources for photo-CVD can be categorized by their coherence, i.e. coherent (lasers) and incoherent (lamps).

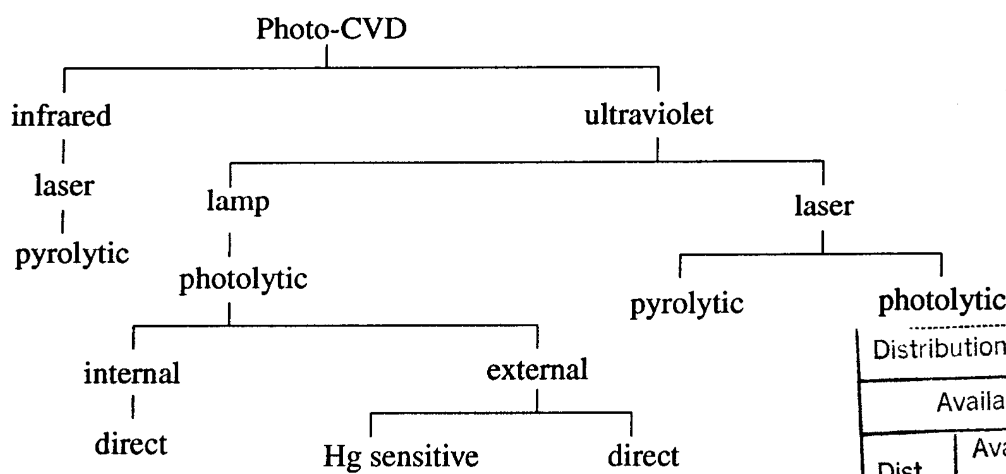

Figure 2. Photo-CVD Techniques

A unique feature of photo CVD diamond growth is that it can use unheated substrates. First diamond growth at room temperature was successfully demonstrated by Rebello, Subramaniam, and Sudarshan 1992 using ArF excimer laser. Multiphoton process was applied to dissociate CO molecules in hyperdilution of H_2 (99.3% H_2/0.7% CO at 8 Torr) via the Cameron bands of CO ($X^1\Sigma^+ \rightarrow a^3\Pi$). The ArF excimer laser was operated at a repetition rate of 20 Hz, a pulsed energy of 100 mJ/pulse, and a pulse duration of about 20 ns. The laser beam was focused to a point approximately 7 mm above the substrate surface and the downstream gas flow provided a transport driving force. Diamond growth with a rate of 5~10 μm was obtained. By the resemblance in morphology of the growth particles with the diamond seeds, it was believed that pure growth, rather than nucleation and growth, was occurring in the experiments. They also concluded that the predissociation of H_2 seems unnecessary to diamond growth by laser activation.

Our interest is to study the diamond growth with a microwave excimer lamp. In our case using the photolysis of water vapor, the multiphoton process may not be necessary. Thus, gas activation with high power incoherent photons can be achieved. The concept of optical confinement, as shown in Figure 3, is proposed to enhance the photolysis of the gas phase for diamond growth. The focal lengths of the quartz lens and the mirrors are L/2, where L is the microwave cavity

length (plus the length of the fittings). With TE_{111} excitation, the maximum power occurs at the central region of the microwave cavity. Therefore, the photons travelling along the proper directions, as indicated, will be focused to the region above the substrate in the diamond growth reactor. Even though only a fraction ($2\Delta\Omega/4\pi$) of light is confined, the UV activation can still be achieved by high power operation and highly reflective mirrors. Actually, the plasma tube also enhances the photon conduction to the growth reactor with a significant factor (~30 for an alumina ceramic tube with ID = 0.8 cm and OD = 1.2 cm) [Lin 1994].

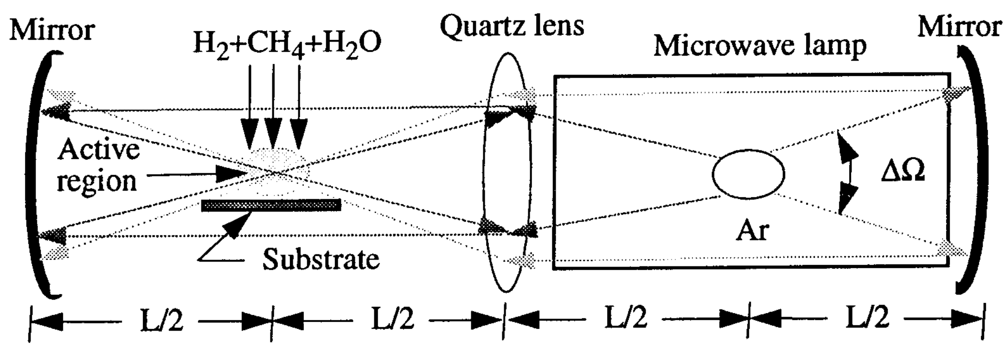

Figure 3. The concept of optical confinement for the photo-CVD reactor using a cylindrical microwave lamp.

A diamond growth reactor, as shown in Figure 4, is designed to demonstrate photo-CVD diamond growth with an incoherent microwave lamp according to the concept of the optical confinement. The reactor is made of a four-way crosses connected to the lens and the microwave lamp. With the internal reflective coating in the microwave cavity, almost all of the photon generated in the cavity can be transported to the reactor. Consider the argon excimer emission at 129 nm with 50% efficiency at a microwave power of 600 W. There is an average intensity of ~300 W/cm^2 (assuming the tube cross section is 1 cm^2). The dissociated rate will be $5.4 \times [H_2O]$ sec^{-1}cm^{-3}, or 5.6×10^{16} sec^{-1}cm^{-3} for 5% of water vapor in a gas mixture of 35 Torr.

REFERENCES

Lin, L.-T. S. 1994 *Microwave and Nuclear Excitations of Alkali Metal Vapors*, Ph. D. Dissertation, University of Missouri-Columbia, Nuclear Engineering Program.

Rebello, J. H. D., Subramaniam, V. V., and Sudarshan, T. S. 1992 "Diamond Growth by Laser-driven Reactions in a CO/H_2 Mixture," *Appl. Phys. Lett.*, **62**(8), 899.

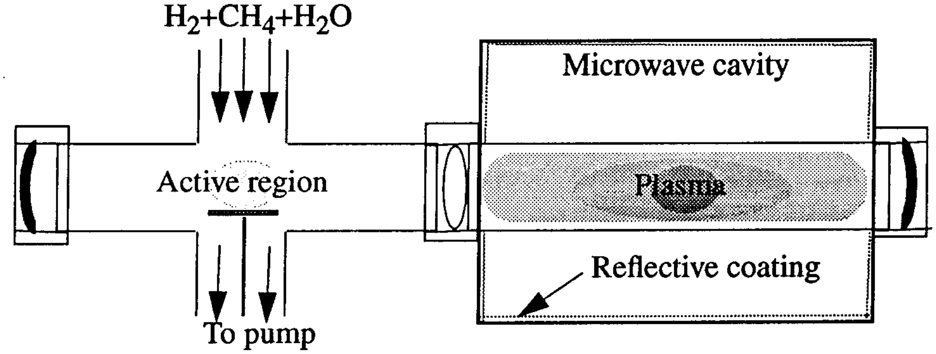

Figure 4. The design the photo-CVD reactor using a cylindrical microwave lamp.

Plan of Next Month

In next month, the experiment with the internal coupling will be performed to demonstrated the UV enhancement of diamond growth in the microwave lamp. The growth conditions will be optimized for high quality films with high growth rate. The experiment with the external coupling will be set up and initiated. The photo-CVD reactor will be constructed.

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